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CLAIMS

What is claimed is:

1. A desulfurization unit comprising:
 - (a) a first adsorbent bed having an inlet for receiving a hydrocarbon fuel stream and comprising an adsorbent selected from the group consisting of metal oxides and zeolites;
 - (b) a nickel adsorbent bed downstream of the first bed; and
 - (c) a guard bed downstream of the first bed and comprising an adsorbent selected from the group consisting of copper-zinc adsorbents, activated alumina, activated carbon, and zeolites.
2. The desulfurization unit of claim 1 wherein the guard bed is downstream of the nickel adsorbent bed.
3. The desulfurization unit of claim 1 wherein the first bed comprises a metal oxide.
4. The desulfurization unit of claim 1 wherein the first bed comprises zinc oxide.
5. The desulfurization unit of claim 1 wherein the nickel adsorbent bed comprises nickel metal.
6. The desulfurization unit of claim 1 wherein the guard bed comprises a copper-zinc adsorbent.

7. The desulfurization unit of claim 1, further comprising a second adsorbent bed fluidly connected to the first bed; the second bed comprising an adsorbent selected from the group consisting of metal oxides and zeolites.

8. The desulfurization unit of claim 7 wherein the desulfurization unit is configured to allow one of the first and second beds to be disconnected during operation of the desulfurization unit while the other of the first and second beds remains in service.

9. The desulfurization unit of claim 8 wherein the first and second beds are fluidly connected in series.

10. The desulfurization unit of claim 8 wherein the first and second beds are fluidly connected in parallel and the desulfurization unit is configured to selectively direct the fuel stream through one of the first and second beds.

11. The desulfurization unit of claim 1, further comprising first and second nickel adsorbent beds downstream of the first bed.

12. The desulfurization unit of claim 11 wherein the desulfurization unit is configured to allow one of the first and second nickel adsorbent beds to be disconnected during operation of the desulfurization unit while the other of the first and second nickel adsorbent beds remains in service.

13. The desulfurization unit of claim 12 wherein the first and second nickel adsorbent beds are fluidly connected in series.

14. The desulfurization unit of claim 12 wherein the first and second nickel adsorbent beds are fluidly connected in parallel and the desulfurization unit is configured to selectively direct the fuel stream through one of the first and second nickel adsorbent beds.

15. The desulfurization unit of claim 1, further comprising first and second guard beds fluidly downstream of the first bed.

16. The desulfurization unit of claim 15 wherein the desulfurization unit is configured to allow one of the first and second guard beds to be disconnected during operation of the desulfurization unit while the other of the first and second guard beds remains in service.

17. The desulfurization unit of claim 16 wherein the first and second guard beds are fluidly connected in series.

18. The desulfurization unit of claim 16 wherein the first and second guard beds are fluidly connected in parallel and the desulfurization unit is configured to selectively direct the fuel stream through one of the first and second guard beds.

19. The desulfurization unit of claim 1, further comprising a heating element for heating the fuel stream and a fuel supply for directing the heated fuel stream to the first bed.

20. The desulfurization unit of claim 1, further comprising heating means for heating at least one of the first bed, nickel adsorbent bed and guard bed.

21. A desulfurization unit comprising:

(a) a vessel having an inlet and outlet for receiving and discharging a hydrocarbon fuel stream;

(b) a first bed disposed in an upstream portion of the vessel, the first bed comprising an adsorbent selected from the group consisting of metal oxides and zeolites;

(c) a second bed disposed in a downstream portion of the vessel, the second bed comprising a nickel adsorbent; and

(d) a guard bed disposed in a downstream portion of the vessel, the guard bed comprising an adsorbent selected from the group consisting of copper-zinc adsorbents, activated alumina, activated carbon, and zeolites.

22. The desulfurization unit of claim 21 wherein the second bed is upstream of the guard bed.

23. The desulfurization unit of claim 21 wherein the first bed comprises zinc oxide.

24. The desulfurization unit of claim 21 wherein the second bed comprises nickel metal.

25. The desulfurization unit of claim 21 wherein the guard bed comprises a copper-zinc adsorbent.

26. The desulfurization unit of claim 21, further comprising heating means for heating at least one of the first, second and guard beds.

27. The desulfurization unit of claim 26 wherein the heating means comprises an electric heating element associated with at least one of the first, second and guard beds.

28. The desulfurization unit of claim 26 wherein the heating means comprises heat exchange elements associated with the vessel.

29. The desulfurization unit of claim 21, further comprising heat exchange elements associated with the vessel for maintaining at least one of the first, second and guard beds within an operating temperature range.

30. A desulfurization unit comprising:
(a) a first bed for adsorbing primary sulfur compounds from a hydrocarbon fuel stream;
(b) a second bed for adsorbing secondary sulfur compounds from the fuel stream; and
(c) a guard bed for adsorbing primary and secondary sulfur compounds from the fuel stream,
wherein the first bed is upstream of the second bed and the guard bed.

31. The desulfurization unit of claim 30 wherein the second bed is upstream of the guard bed.

32. The desulfurization unit of claim 30 wherein the first bed comprises an adsorbent selected from the group consisting of metal oxides and zeolites.

33. The desulfurization unit of claim 30 wherein the first bed comprises zinc oxide.

34. The desulfurization unit of claim 30 wherein the second bed comprises a nickel adsorbent.

35. The desulfurization unit of claim 30 wherein the guard bed comprises an adsorbent selected from the group consisting of copper-zinc adsorbents, activated alumina, activated carbon, and zeolites.

36. The desulfurization unit of claim 30 wherein the guard bed comprises a copper-zinc adsorbent.

37. The desulfurization unit of claim 30, further comprising a heating unit upstream of the first bed for heating the fuel stream.

38. The desulfurization unit of claim 30, further comprising a heat exchange element associated with at least the first bed.

39. A process for reducing the sulfur content of a hydrocarbon fuel stream comprising primary sulfur compounds to ≤ 1 ppm, the process comprising:

(a) heating the fuel stream to a temperature greater than or equal to the thermal decomposition temperature of at least a portion of the primary sulfur compounds;

(b) directing the fuel stream to a first bed comprising an adsorbent selected from the group consisting of metal oxides and zeolites;

(c) directing the heated fuel stream to a nickel adsorbent bed downstream of the first bed; and

(d) directing the heated fuel stream to a guard bed downstream of the second bed, the guard bed comprising an adsorbent selected from the group consisting of copper-zinc adsorbents, activated alumina, activated carbon, and zeolites.

40. The process of claim 39 wherein the fuel stream is heated before being directed to the first bed.

41. The process of claim 39 wherein the fuel stream is heated within the first bed.

42. The process of claim 39 wherein the fuel stream is heated to at least 150°C.

43. The process of claim 39 wherein the fuel stream is heated to at least 200°C.

44. The process of claim 39 wherein the fuel stream is heated to at least 225°C.

45. The process of claim 39 wherein the fuel stream is heated to at least 250°C.

46. The process of claim 39 wherein the first bed comprises a metal oxide.

47. The process of claim 39 wherein the first bed comprises zinc oxide, the guard bed comprises a copper-zinc adsorbent, and the first bed, nickel adsorbent bed and the guard bed are maintained at an operating temperature within the range of about 150°C to about 750°C.

48. The process of claim 47 wherein the operating temperature is within the range of about 150°C to about 400°C.

49. The process of claim 47 wherein the operating temperature is greater than about 250°C.

50. The process of claim 47 wherein the operating temperature is within the range of about 260°C and about 400°C.

51. A process for reducing the sulfur content of a hydrocarbon fuel stream comprising secondary sulfur compounds to ≤ 1 ppm, the process comprising:

(a) directing the fuel stream to a first bed comprising an adsorbent selected from the group consisting of metal oxides and zeolites;

(b) directing the fuel stream to a guard bed downstream of the first bed, the guard bed comprising an adsorbent selected from the group consisting of copper-zinc adsorbents, activated alumina, activated carbon, and zeolites; and

(c) directing the fuel stream to a third bed downstream of the guard bed, the third bed comprising a nickel adsorbent.

52. The process of claim 51 wherein the fuel stream in the first bed is at a temperature of at least 150°C.

53. The process of claim 51 wherein the fuel stream in the first bed is at a temperature of at least 200°C.

54. The process of claim 51 wherein the fuel stream in the first bed is at a temperature of at least 250°C.

55. The process of claim 51 wherein the first bed comprises zinc oxide, the guard bed comprises a copper-zinc adsorbent, and the third bed comprises nickel metal.

56. A fuel cell electric power generation system comprising:
(a) a fuel processing system for converting a hydrocarbon fuel stream to a reformat stream comprising hydrogen, the fuel processing system comprising a desulfurization unit comprising:

- (i) a metal oxide adsorbent bed;
- (ii) a nickel metal adsorbent bed downstream of the metal oxide bed;

and

- (iii) a copper-zinc guard bed downstream of the metal oxide bed; and
- (b) a fuel cell stack for receiving the reformat and connectable to an electrical load.

57. The power generation system of claim 56, further comprising a vessel having an inlet and outlet for receiving and discharging the fuel stream, wherein the metal oxide adsorbent bed, nickel metal adsorbent bed and the guard bed are disposed in the vessel.

58. The power generation system of claim 56 wherein the metal oxide adsorbent bed comprises zinc oxide.

59. The power generation system of claim 56, further comprising a heating unit located upstream of the metal oxide adsorbent bed for heating the fuel stream.

60. The power generation system of claim 56, further comprising heating means for heating the metal oxide adsorbent bed.

61. The power generation system of claim 56 wherein the fuel processing system further comprises a pre-oxidizer located upstream of the desulfurization unit.

62. The power generation system of claim 56 wherein the fuel processing system further comprises a steam reformer located downstream of the desulfurization unit.

63. The power generation system of claim 56 wherein the fuel processing system further comprises an autothermal reformer located downstream of the desulfurization unit.

64. A method of operating a fuel cell electric power generation system comprising

a fuel processing system for converting a hydrocarbon fuel stream to a reformat stream comprising hydrogen, the fuel processing system comprising a desulfurization unit, the desulfurization unit comprising

a metal oxide adsorbent bed,

a nickel metal adsorbent bed downstream of the metal oxide bed, and

a copper-zinc guard bed downstream of the metal oxide bed, and

a fuel cell stack for receiving the reformat and connectable to an electrical load, the method comprising:

(a) directing the fuel stream to a first bed comprising an adsorbent selected from the group consisting of metal oxides and zeolites, and having a first minimum operating temperature;

(b) directing the fuel stream to a downstream second bed comprising a nickel adsorbent, and having a second minimum operating temperature;

(c) directing the fuel stream to a downstream guard bed comprising an adsorbent selected from the group consisting of copper-zinc adsorbents, activated alumina, activated carbon, and zeolites, and having a third minimum operating temperature lower than the first and second minimum operating temperatures; and

(d) heating the fuel stream to a process temperature that is higher than or equal to any of the first, second and third minimum operating temperatures.

65. The method of claim 64 wherein, during a first period, the fuel stream is at an initial temperature at or above the third minimum operating temperature and below at least one of the first and second minimum operating temperatures.

66. The method of claim 65 wherein the third operating temperature is about 20°C.

67. The method of claim 66 wherein the initial temperature is less than about 150°C.

68. The method of claim 64 wherein the process temperature is at least about 260°C.

69. The method of claim 64 wherein the first minimum operating temperature is about 150°C.

70. The method of claim 64 wherein the first minimum operating temperature is about 260°C.

71. The method of claim 64 wherein the second minimum operating temperature is about 150°C.

72. The method of claim 64 wherein the second minimum operating temperature is about 260°C.

73. The method of claim 64 wherein step (d) precedes step (a).

74. The method of claim 64 wherein step (a) and step (d) occur simultaneously.

75. The method of claim 64 wherein step (b) precedes step (c).

FOOTNOTES